# *Waste management, informal recycling, environmental pollution and public health*

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# Waste management, informal recycling, environmental pollution and public health

Hong Yang,[1,2] Mingguo Ma,[1] Julian R. Thompson,[3] Roger J. Flower [3]

[1] Chongqing Engineering Research Center for Remote Sensing Big Data Application, Chongqing Key Laboratory of Karst Environment, School of Geographical Sciences, Southwest University, Chongqing 400715, China

[2] Department of Geography and Environmental Science, University of Reading, Reading RG6 6AB, UK

[3]UCL Department of Geography, University College London, London, WC1E 6BT, UK

Correspondence to Hong Yang (hongyanghy@gmail.com) or Mingguo Ma (mmg@swu.edu.cn)

## ABSTRACT

With rapid population growth, especially in developing countries, the generation of waste is increasing at an unprecedented rate. For example annual global waste arising from waste electrical and electronic equipment (WEEE) alone will have increased from 33.8 million to 49.8 million tons between 2010 and 2018. Despite incineration and other waste treatment techniques, landfill still dominates waste disposal in developing countries. There is usually insufficient funding for adequate waste management in these countries and uptake of more advanced waste treatment technologies is poor. Without proper management, many landfills represent serious hazards as typified by the landslide in Shenzhen, China on December 20, 2015. In addition to formal waste recycling systems, approximately 15 million people around the world are involved in informal waste recycling, mainly for plastics, metals, glass, and paper. This review examines emerging public health challenges, in particular, within developing countries, associated with the informal sector. Whilst informal recyclers contribute to waste recycling and reuse, the relatively primitive techniques they employ, combined with improper management of secondary pollutants, exacerbate environmental pollution of air, soil and water. Even worse, insufficient occupational health measures exposes informal waste workers to a range of pollutants, injuries, respiratory and dermatological problems, infections, and other serious health issues that contribute to low life expectancy. Integration of the informal sector with its formal counterparts could improve waste management while addressing these serious health and livelihood issues. Progress in this direction has already been made in several Latin American countries where integrating the informal and formal sectors has had a positive influence on both waste management and poverty alleviation.

## INTRODUCTION

With rapidly increasing populations and unprecedented urbanization rates, waste generation is growing rapidly, particularly in cities and especially in emerging countries. Effective waste management, especially of toxic material, is a major challenge for global sustainable development.[1] A range of methods are available for the disposal or treatment of waste including landfill, incineration, composting and recycling. Landfill remains the most widely used approach in the developing world due to its low cost. However, improper management can result in major health and environmental problems. Particular emerging hazards are dangerous and poorly managed landfill slides.[2] For example, management failures led to the collapse of a landfill in Shenzhen, China on December 20, 2015 that killed 73 people.[3, 4] A similar collapse in Bandung, Java, Indonesia, in February 2005 was responsible for 140 deaths.[5]

The formal, government funded, sector is responsible for most waste collection and treatment services in developed countries. However, in many developing nations limited resources means that the formal sector cannot keep pace with rapid expansion of waste production. The informal sector (the so called waste pickers and scavengers in some countries) has grown as a result. Informal waste recyclers collect, transport and trade waste in almost all developing countries.[6] It is estimated that the informal waste sector supports around 15 million people, particularly within large and relatively wealthy cities.[7]

Informal waste recyclers are subsistence workers using relatively primitive technologies to process and recycle a wide variety of waste material from food waste to heavy metals. They can play a key role in recycling material but poor regulation often results in increased environmental pollution through release of an array of secondary pollutants.[8] Insufficient occupational health exposes informal waste recyclers to a host of health damaging factors.[4] With rapid urbanization and the diversification of waste, especially waste electrical and

electronic equipment (WEEE), health risks facing informal waste recyclers from toxins is increasing. These concerns are exemplified by growing health-related problems facing waste workers in Guiyu, South China, the so-called "electronics graveyard of the world".[9]

Some studies of informal waste recyclers[10-12] and WEEE[13-15] have been undertaken whilst plastic waste pollution, particularly microplastics, have received more attention recently[16, 17]. The current study focuses on important emerging public health challenges facing informal recyclers, particularly in developing countries. It also outlines the future challenges for the informal waste sector.

## INCREASING WASTE PRODUCTION WITH GROWING POPULATIONS AND EXPANDING URBANIZATION

Waste is continuously generated by human activities. Sources of solid waste include industry, construction, commerce, the services and domestic sectors and individual households. The nature of the waste generated will vary from location to location and through time in response to the dominant human activities taking place. It is estimated that globally approximately 11 billion tons of solid waste was produced in 2011.[18] Increasing populations, rapid urbanization and economic development in emerging countries mean that waste production is increasing at an unparalleled rate. China and India are the most populous economically emerging countries and waste problems in their urban and peri-urban areas are amongst the most acute. Municipal solid waste frequently exceeds society's capacity for safe management.[19] Expanding urban infrastructure, for example roads, bridges, and rapid transport systems are generating increasing volumes of construction and demolish wastes (CDW). For example, 87,000 $m^3$ of CDW was produced during construction of Futian station, Asia's largest underground station, in Shenzhen, China, the city where the calamitous landfill slide occurred in 2015.[3]

Rapid development of information and communications technology [17] means that, globally, WEEE is one of the fastest growing wastes.[20] In 2014 around 42 million tonnes of WEEE was generated worldwide.[21] Despite low average per capita WEEE generation of only 3.7 kg year$^{-1}$, Asia was the largest continental contributor, accounting for nearly 38% of global WEEE (16 million tonnes in 2014). Whilst between 2010 and 2018 the global population is projected to have increased by around 8%, total and per capita WEEE generation are set to grow by approximately 47% and 34%, respectively (Figure 1).[21] The increasing severity of problems associated with WEEE disposal in both developing and developed countries is creating both governmental and the public concern.

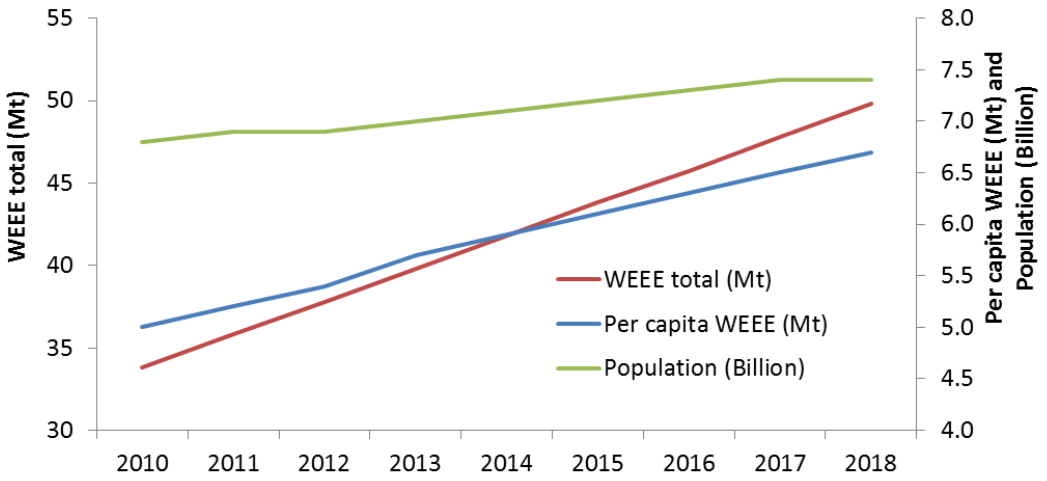


**Figure 1** Increasing global production (total and per capita) of waste electrical and electronic equipment (WEEE) and human population: 2010–2018. (Note: Data are from reference [21])

An additional concern is overuse of plastics and resulting plastic waste. Worldwide plastics and polymer consumption has grown at an average rate of 10% per year since the 1990s.[17] Rates of increase are particularly large in emerging economies. Approximately 275 million tons of plastic waste was generated in global coastal cities in 2010 with China contributing

more than 25% of this total. [16] It is estimated that between 4.8 and 12.7 million tons entered the ocean in 2010. Without improvements in waste management, generation of plastic waste is expected to grow by an order of magnitude by 2025. Risks associated with plastic waste, especially microplastics (plastic debris <5mm diameter), to marine wildlife and human health are growing concerns amongst researchers and the public alike.[22]

## INFORMAL WASTE RECYCLING

Lack of funding within rapidly expanding cities of many developing countries results in extensive informal waste recycling. In contrast to the formal sector, informal waste recycling is undertaken without government financial support and may not be recognised by the public as providing a valuable service.[23]

In common with formal waste management, the informal sector comprises players at the different stages of waste recycling (Figure 2).[17] For example, waste pickers choose and collect valuable items from locally sourced household, commercial and industrial waste or from waste imported from overseas. These waste pickers form the base of the informal waste sector (Figure 2) and are characteristically from poor, disadvantaged, vulnerable and/or marginalised social groups.[17] They are characterised by low levels of organization, technology and capital, as well as non-compliance to rules and regulations related to tax, minimum wages, workers safety and environmental protection. Although informal waste recycling is not usually recognized as a legal occupation in many countries, it provides large societal benefits in terms of waste management and lessening pressure on resources used in the production of material goods.[24]

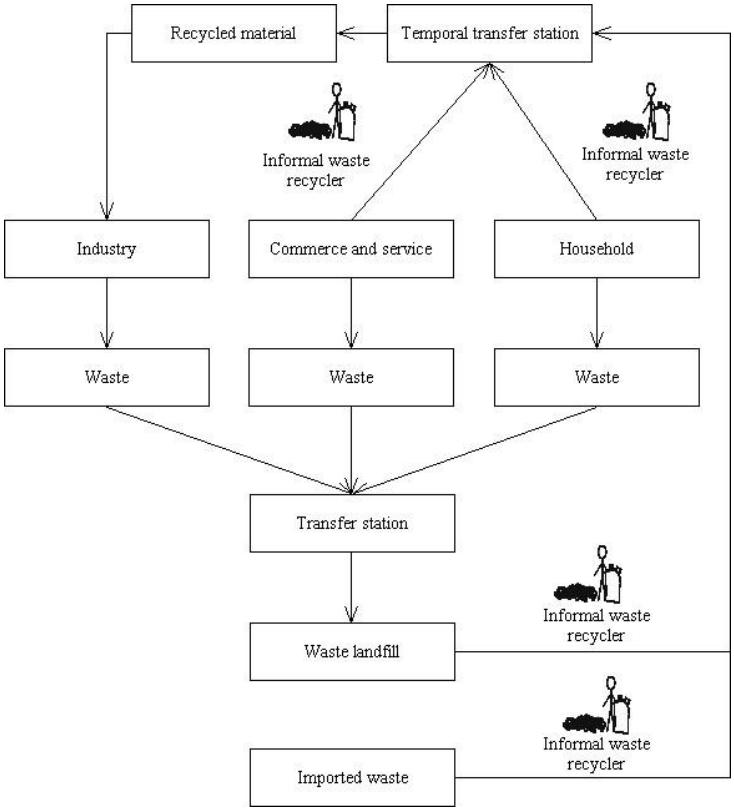


**Figure 2** Involvement of informal waste recyclers in waste management. (Modified from reference [51]).

Informal waste collectors sort and collect valuable waste from industry, the commercial and service sectors, households, imported waste and landfill sites. Sorted waste is transported and sold to both government and non-government funded transfer stations. In non-government funded transfer stations, informal waste recyclers further sort waste and identify and extract valuable recyclable material.

It is estimated that more than 15 million people are involved in informal waste recycling, mostly in developing countries.[7] China has the largest number [11, 25] and between 0.6% and 0.9% of the urban population, or 3.3–5.6 million people, are involved in informal waste collection and recycling activities in Chinese cities.[11] In Shanghai alone the informal recycling sector involves nearly 200,000 people and accounts for approximately 17–38% of municipal recycling activities.

## MATERIALS RECYCLED BY INFORMAL WASTE RECYCLERS

Although there are variations between regions and countries, materials most frequently recycled by the informal sector are paper and cardboard, scrap metal (especially aluminium, steel, tin), glass, plastic (polyethylene terephthalate, PET) bottles, rubber, wood, textiles and food waste.[6] Metal, paper and PET are usually preferred due to their large recycling potential and long life spans.

WEEE makes up a growing proportion of waste recycled by the informal sector due to the potentially high value of material that can be recovered. However, recycling methods and poor occupational health means that WEEE poses some of the largest health risks to informal recyclers.[13] Informal WEEE recycling activities are widespread and are undertaken in many places around the world although toxic exposure patterns vary according to recycling methods and processes. A notorious example of informal WEEE recycling is Guiyu, an agglomerate of four villages in Guangdong, South China (Figure 3, a). Since 1995, nearly 6000 family workshops have processed approximately 1.6 million tons of WEEE annually.[9, 26] Guiyu has become the world's largest WEEE dismantling and recycling site. Workers manually break open electronics and strip away parts for reuse including chips and valuable metals (Figure 3, b and c). Workers "cook" circuit boards to remove chips and burn wires and other plastics to liberate metals such as copper. Highly dangerous acid baths are used along the riverbanks to extract gold from microchips (Figure 3, d).


**Figure 3** Informal waste recyclers working on waste electrical and electronic equipment (WEEE) and associated environmental and health risks in Guiyu, China.

(A) Guiyu in Guangdong, South China; (B) WEEE are preliminarily processed by hand; (C) Primitive technology is used to extract valuable heavy metals from WEEE; (D) The river in Guiyu is polluted by secondary waste produced by WEEE recycling; and (E) Families live near WEEE recycling works with poor protection from associated dangers to health.

Image credits: B, C, D, E are reproduced with permission from www.tuchong.com.

Plastic, especially bottles, is easily collected and sold by informal recyclers. In many cities, for example Delhi and Beijing, waste plastic trading is well established with many processing units.[17] However, most of this plastic is recycled in a crude manner by informal setups. Elements such as heavy metals, bromine, and antimony are added to polymers as pigments, fillers, UV stabilizers, and flame retardants.[17] Inappropriate recycling of plastic waste risks contamination by such additives.

## ENVIRONMENTAL POLLUTION

Crude methods with insufficient environmental protection can generate secondary pollutants. Environmental pollution from informal waste recycling is diverse in toxicants and levels of exposure, contaminating air, water and soil. [27-29] Contamination is widespread and can reach extremely high levels near to informal recycling sites. Toxic heavy metals, for example lead (Pb) and chromium (Cr), and persistent organic pollutants (POPs) including polycyclic aromatic hydrocarbons (PAHs) and brominated flame retardants are common contaminants.[13]

In Agbogbloshie, a WEEE processing site in Accra, Ghana, the average soil concentrations of Pb (953.21 mg $kg^{-1}$) , Cr (296.60 mg $kg^{-1}$), barium (Ba) (627.66 mg $kg^{-1}$), and copper (Cu) (1387.96 mg $kg^{-1}$) far exceed regulatory limits, for example the world-wide-accepted Dutch and Canadian standards. [30] Similarly, in Mandoli, Delhi, India, concentrations of heavy metals, particularly Cu (115.50 mg $kg^{-1}$), Pb (2645.31 mg $kg^{-1}$) and zinc (Zn) (776.84 mg $kg^{-1}$), in surface soil of WEEE recycling sites were much higher than those in reference sites. [31] Concentrations of total mono- to hepta-brominated diphenyl ether homologues in soils near WEEE dumping sites in Guiyu, China, were 1140 and 1169 µg $kg^{-1}$ dry wt, approximately 10–60 times higher than in any other contaminated sites.[14] Cu, Pb and Zn were the most abundant metals and their concentrations exceeded the new Dutch list action values of 190 mg $kg^{-1}$ at most sites (Table 1).[14] This environmental pollution has drawn wide attention and

Guiyu has been selected as one of China's first pilot circular-economy sites to mitigate contamination and improve WEEE recycling.[32]

**Table 1** Average concentrations of heavy metal samples collected from Guiyu, South China (unit: mg $kg^{-1}$)

| Sites | | Pb | Cu | Zn |
|---|---|---|---|---|
| Soil | Burnt plastic dump sites | 104.2 | 490.7 | 241.5 |
| | Waste printer roller dump sites | 189.9 | 711.9 | - |
| River sediment | | 94.3 | 531.2 | 240.1 |

Note: Data are from reference[33] which provides details on sampling and laboratory measurements.

## HEALTH ISSUES

A wide range of health issues confronts those involved in the informal waste sector (Table 2). Working on waste dumps and landfill sites is inherently dangerous and there are frequent accidents including fires, explosions and, as at Shenzhen, debris slides.[4] Most informal waste recyclers do not wear protective equipment such as gloves and boots because of their relatively high costs and lack of risk awareness. Recyclers often prefer to work barehanded for greater tactility but risk sharp trauma [7] especially from glass and hospital waste containing syringes (Table 3).[24, 34] Pickers are often in direct contact with toxic materials as well as human/animal wastes.

Health risks to informal waste workers and their families associated with heavy metals has drawn particular attention. High blood concentrations of lead have been found in recyclers working in landfills.[35, 36] Lead and dioxin related-compounds have been discovered in higher concentrations within the breast milk of female waste recyclers.[37] Children and developing foetuses are particularly susceptible to heavy metal effects (Figure 3, e). For example, the stillbirth rate in Guiyu was 4.6 times that of control sites, while blood lead concentrations in neonates were 4.8 times the control.[9] Exposure to hazardous plastic additives including brominated flame retardants (BFRs) and heavy metals are all implicated in nervous and reproductive system problems, behavioural changes and cancer.[38]

Informal waste workers are also prone to inhaling gaseous emissions, bio-aerosols and micro-organisms (i.e. automobile fumes, dust, mould, and fungi). Waste pickers in landfills can be exposed to gas emissions including methane ($CH_4$) and hydrogen sulfate ($H_2S$), as well as vehicular emmisions,[39] causing respiratory, dermatological and eye problems.[24] They are also more prone to common illnesses (flu, bronchitis, ulcers and others), musculoskeletal difficulties and vermin transmitted disease.[34, 40]

Insanitary working conditions and lack of washing facilities mean that informal waste recyclers can transport toxic materials to their homes and families.[34, 41] Waste dumps and landfills are breeding grounds for pathogenic organisms responsible for dengue, leishmaniasis, diarrhoea, typhoid, anthrax, cholera, malaria and a variety of skin disorders (Table 2).

In addition, most informal waste workers and their families are marginalised and suffer social exclusion.[7] Coupled with financial insecurity, perceived shame and humiliation, this can lead to severe psychological damage[7] which in turn has wide-ranging implications for the local communities.

**Table 2** Key health hazards for informal recycler communities

| Health hazards | Description |
|---|---|
| Chemical | Toxic chemicals (e.g. heavy metals and brominated flame retardants). |
| Hygiene | Lack of hand washing facilities or proper toilets. |
| Disease | Headache, respiratory issues, dermatological problems, eye infections, flu, bronchitis, ulcers, high blood pressure, musculoskeletal injuries (i.e. chronic back ache and soreness in arms, legs and shoulders), typhoid fever, tuberculosis, dysentery, poliomyelitis, malaria, dengue, leishmaniasis, diarrhoea, anthrax, cholera. |
| Accident | Falls and others leading to cuts and bone breaks, fires (from burning of waste), explosions, landfill slides |
| Psychological | Insecurity, perceived shame, humiliation. |

(Modified from references [7, 17, 24, 34, 40])

**Table 3** Symptom / health concerns and the causes of cuts / other injuries reported in a survey of informal waste recyclers in Bangkok, Thailand

| Symptom / health concern | Percentage of participants |
|---|---|
| Headache | 36.0 |
| Diarrhoea | 12.8 |
| Respiratory related | 8.4 |
| Skin disease | 5.1 |
| Other | 2.0 |
| **Cuts or injuries from:** | |
| Glass | 88.2 |
| Needle | 72.7 |
| Metal | 24.9 |
| Bamboo | 30.3 |

(Note: Data from reference[42] which provides details on patients and survey)

## MEASURES TO IMPROVE THE WELLBEING OF INFORMAL WASTE RECYCLERS

There is range of policy, economic and industrial hygiene measures that can improve the wellbeing of informal recyclers. Green chemistry, improved recyclability of products and the removal of toxicants before recycling are fundamentally important.[43] Poverty alleviation through adequate funding of the services provided by informal recyclers is a necessity. Hence, modernising waste management systems will need to increasingly consider informal waste systems.[11]

Proper landfill management is important to prevent scavengers accessing toxic waste sites. In addition, new low-cost technologies developed to minimize health risks during waste recycling need to be adopted by the informal sector. An example is salt water floatation for separating plastics containing toxic BFRs.[44] Governmental or NGO funding can provide equipment such as battery-driven handcarts, hand tools, safety wear and uniforms.[45] Uniforms and ID cards formalise the appearance of informal workers and thereby foster a better relationship with the public that can build self-confidence and self-esteem amongst informal workers.[34]

Government training of informal sector workers can provide more professional recycling knowledge, such as standardised classification and processing methods for different waste, the laws and regulations concerning recycling and development plans for recycling systems. In China, relevant new regulations and laws have been implemented. For example, the Law on Circular Economy Promotion (effective from 1/1/2009) includes a legal framework for waste reduction, reuse and recycling whilst China's new Environmental Protection Law also highlights waste management.[46] In this July, China released the regulation to gradually stop to import soil wastes, especially WEEE. Strict enforcement of such laws and regulations by both formal and informal recyclers will be indispensable in improving waste recycling and protecting workers.[47]

The creation of cooperatives and associations by informal recyclers has proven to be effective. The strengthening of these cooperatives and group networks can facilitate transfer of knowledge regarding proper waste handling and processing, related regulations and laws, environmental protection, sanitation, hygiene and health.[7] Such cooperatives also legitimize the work as a public service, allowing social programs, such as extended health care and childcare, to be funded. In some countries these cooperatives have combined into larger regional or national movements.[48] In Pune, India, SWaCH (Solid Waste Collection and Handling), a cooperative of approximately 1,500 waste pickers, serves 200,000 households.[45] In Brazil, Coopamare is one of the most successful cooperatives [49] and the country has one of the largest and best established national movements of waste pickers.[6, 48]

There are characteristically more women than men working in the informal recycling sector. Support for the sector should, therefore, reflect this gender imbalance. For example, Women in Informal Employment: Globalising and Organising (WIEGO), is a global action research-policy network and waste picker support organisation focussed on women in the informal waste sector.[48] WIEGO has been actively involved in the First World Conference of

Waste Pickers (2008), the Third Latin American Conference of Waste Pickers (2008) and the National Day of the Waste Picker in Colombia (since 2008).

## COLLABORATION BETWEEN INFORMAL AND FORMAL SECTORS

Efforts have been made to integrate the formal and informal waste sectors. Effective integration can increase recycling rates, improve livelihoods and occupational and environmental health, as well as reducing waste management costs. Research in Brazil, Egypt, and India has demonstrated that integration can increase informal sector revenues and reduce total waste system costs for the formal sector.[45] A study of the state-of-the-art "InteRa" model for integrating the informal sector within waste management systems in developing countries found similar win-win outcomes.[50] Successful development of integrated systems requires involvement of a wide variety of stakeholders beyond the formal and informal waste management sectors including federal, state and local governments, environment / development agencies and NGOs, academics, and financial institutions.[49,51]

## CHALLENGES AND FUTURE RESEARCH

Improving the health of those involved in the informal waste sector is a major challenge. International collaboration, for example thorough the Sustainable Development Goals (SDGs), will be vital for improving waste management, including addressing environmental pollution problems, and for enhancing wellbeing of informal waste recyclers. Whilst there are promising schemes for integrating the informal sector with formal waste management , especially in Latin America[45], these are still in their infancy in many countries. Probably the biggest challenges are to raise awareness of the issues facing the informal sector and to change attitudes to waste pickers in many traditional cultures. Governments and the media need to acknowledge the often vital contribution the informal sector can make to waste recycling. Changed attitudes would contribute to establishing support schemes for workers,

better integration of informal workers in waste management and establishing professional informal sector recycling enterprises.[45]

Current regulatory trends and capital investments pave the way for large recycling firms to operate. One result is that small players become excluded from the industry. Increasing pressure for automation and updated sorting techniques make it much more difficult for small enterprises to compete and informal workers are excluded from waste sites. There are clear health and safety benefits but displaced informal workers need to be either incorporated into new business schemes or be compensated to help alleviate poverty. Waste management decisions should also take into account who would most benefit from the revenues from recyclables and how to improve disposal of non-recyclable, often toxic, material.[11] High market prices can boost incentives for informal recycling and increase collection rates of recyclable material, while also benefitting the livelihoods of many individuals through employment. Conversely, low prices are challenging for informal waste recyclers.

## CONCLUSIONS

With increasing populations and economic development, the quantity of waste being generated is rapidly increasing, creating an array of management and environmental issues. In many developing nations, insufficient funding for the formal waste sector means that globally around 15 million informal waste workers sort, collect, transport and trade waste. This informal sector makes major contributions to waste recycling and reuse. Heavy metals, plastic and paper are the main targets for informal waste recyclers. Unfortunately, relatively primitive recycling methods are responsible for major environmental pollution and human health problems. Some efforts have been made to integrate the informal waste sector with the formal sector, especially in Latin America. However, in many countries, the informal sector is still regarded as undesirable and often a nuisance despite the services it provides.

Raising awareness of the valuable contributions made by the informal sector and changing public attitudes to those involved is needed in many countries. International collaboration, for example thorough the Sustainable Development Goals (SDGs), will be indispensable for improving waste management and the wellbeing of those participating in informal waste recycling.

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## REFERENCES

1 Hoornweg D, Bhada-Tata P, Kennedy C. Waste production must peak this century. *Nature* 2013;**502**:615-7.

2 Yang H, Huang X, Thompson JR*, et al.* The crushing weight of urban waste. *Science* 2016;**351**:674-.

3 Yang H, Xia J, Thompson J, R*, et al.* Urban construction and demolition waste and landfill failure in Shenzhen, China. *Waste Manage* 2017;**63**:393-6.

4 Yang H, Huang XJ, Thompson JR*, et al.* Chinese landfill collapse: urban waste and human health. *Lancet Glob Health* 2016;**4**:e452.

5 Lavigne F, Wassmer P, Gomez C*, et al.* The 21 February 2005, catastrophic waste avalanche at Leuwigajah dumpsite, Bandung, Indonesia. *Geoenviron Disasters* 2014;**1**:1-12.

6 Ezeah C, Fazakerley JA, Roberts CL. Emerging trends in informal sector recycling in developing and transition countries. *Waste Manage* 2013;**33**:2509-19.

7 Binion E, Gutberlet J. The effects of handling solid waste on the wellbeing of informal and organized recyclers: a review of the literature. *Int J Occup Env Heal* 2012;**18**:43-52.

8 Robinson BH. E-waste: an assessment of global production and environmental impacts. *Sci Total Environ* 2009;**408**:183-91.

9 Xu XJ, Yang H, Chen AM*, et al.* Birth outcomes related to informal e-waste recycling in Guiyu, China. *Reprod Toxicol* 2012;**33**:94-8.

10 Mbeng L, O. Informal Waste Recovery and Recycling: Alleviating Poverty, Environmental Pollution and Unemployment in Douala, Cameroon. *J Sci Res Rep* 2013;**2**:474-90.

11 Linzner R, Salhofer S. Municipal solid waste recycling and the significance of informal sector in urban China. *Waste Manage Res* 2014;**32**:896-907.

12 Nzeadibe TC, Anyadike RNC, Njoku-Tony RF. A mixed methods approach to vulnerability and quality of life assessment of waste picking in urban Nigeria. *Appl Res Qual Life* 2012;**7**:351-70.

13 Grant K, Goldizen FC, Sly PD*, et al.* Health consequences of exposure to e-waste: a systematic review. *Lancet Glob Health* 2013;**1**:E350-E61.

14 Leung A, Cai ZW, Wong MH. Environmental contamination from electronic waste recycling at Guiyu, southeast China. *J Mater Cycle Waste Manage* 2006;**8**:21-33.

15 Frazzoli C, Orisakwe OE, Dragone R*, et al.* Diagnostic health risk assessment of electronic waste on the general population in developing countries' scenarios. *Environ Impact Assess Rev* 2010;**30**:388-99.

16 Jambeck JR, Geyer R, Wilcox C*, et al.* Plastic waste inputs from land into the ocean. *Science* 2015;**347**:768-71.

17 Toxics Link. *WEEE plastic and brominated flame retardants: A report on WEEE plastic recycling*. New Delhi, India: Toxics Link 2016.

18 Song Q, Li J, Zeng X. Minimizing the increasing solid waste through zero waste strategy. *J Clean Prod* 2015;**104**:199-210.

19 Hester RE, Harrison RM. *Environmental and health impact of solid waste management activities*. Cambridge, UK: Royal Society of Chemistry 2002.

20 EC Directive. Directive 2012/19/EU of the European Parliament and of the Council of 4 July 2012 on waste electrical and electronic equipment (WEEE). *Off J EU* 2012;**L197**:38-69.

21 Baldé C, P, Wang F, Kuehr R*, et al. The global e-waste monitor 2014: Quantities, flows and resources*. United Nataions University, IAS - SCYCLE: Bonn, Germany 2015.

22 Thompson RC, Moore CJ, Vom Saal FS*, et al.* Plastics, the environment and human health: current consensus and future trends. *Philos T Roy Soc B* 2009;**364**:2153-66.

23 Gunsilius E, Chaturvedi B, Scheinberg A*, et al. The economic aspects of the informal sector in solid waste management*. Eschborn, Germany: GTZ (German Technical Cooperation) 2011.

24 Wilson DC, Velis C, Cheeseman C. Role of informal sector recycling in waste management in developing countries. *Habitat Int* 2006;**30**:797-808.

25 Mathews JA, Tan H. Circular Economy: Lessons from China. *Nature* 2016;**531**:440-2.

26 Chi XW, Streicher-Porte M, Wang MYL*, et al.* Informal electronic waste recycling: A sector review with special focus on China. *Waste Manage* 2011;**31**:731-42.

27 Yang H, Huang X, Thompson JR*, et al.* Soil pollution: urban brownfield. *Science* 2014;**344**:691-2.

28 Yang H, Flower RJ, Thompson JR. Sustaining China's water resources. *Science* 2013;**339**:141-.

29 Chang N-B, Shoemaker CA, Schuler RE. Solid waste management system analysis with air pollution and leachate impact limitations. *Waste Manage Res* 1996;**14**:463-81.

30 Nartey KV. Environmental and Health Impacts of Informal E-waste Recycling in Agbogbloshie, Accra, Ghana: Recommendations for Sustainable Management. Bonn, Germany: Rheinische Friedrich-Wilhelms-Universität Bonn 2016.

31 Pradhan JK, Kumar S. Informal e-waste recycling: environmental risk assessment of heavy metal contamination in Mandoli industrial area, Delhi, India. *Environ Sci Pollut Res* 2014;**21**:7913-28.

32 Wang ZH, Zhang B, Guan DB. Take responsibility for electronic-waste disposal. *Nature* 2016;**536**:23-5.

33 Liu XB, Tanaka M, Matsui Y. Electrical and electronic waste management in China: progress and the barriers to overcome. *Waste Manage Res* 2006;**24**:92-101.

34 Gutberlet J, Baeder AM. Informal recycling and occupational health in Santo André, Brazil. *Int J Environ Health Res* 2008;**18**:1-15.

35 Sarkar P. Solid waste management in Delhi – a social vulnerability study. *Proceedings of the third international conference on environment and health*. Chennai, India 2003:451-64.

36 Suplido ML, Ong CN. Lead exposure among small-scale battery recyclers, automobile radiator mechanics, and their children in Manila, the Philippines. *Environ Res* 2000;**82**:231-8.

37 Kunisue T, Watanabe M, Iwata H*, et al.* Dioxins and related compounds in human breast milk collected around open dumping sites in Asian developing countries: bovine milk as a potential source. *Arch Environ Contam Toxicol* 2004;**47**:414-26.

38 Valavanidis A, Iliopoulos N, Gotsis G*, et al.* Persistent free radicals, heavy metals and PAHs generated in particulate soot emissions and residue ash from controlled combustion of common types of plastic. *J Hazard Mater* 2008;**156**:277-84.

39 U.S. Environmental Protection Agency (EPA). *Guidance for evaluating landfill gas emissions from closed or abandoned facilities*. Washington, DC, USA: U.S. EPA. Office of Research and Development 2005.

40 Matter A, Dietschi M, Zurbrugg C. Improving the informal recycling sector through segregation of waste in the household - The case of Dhaka Bangladesh. *Habitat Int* 2013;**38**:150-6.

41 Yang H, Wright JA, Gundry SW. Improving access to sanitation in China. *Nature* 2012;**488**:32-32.

42 Kungskulniti N, Pulket C, Miller FD*, et al.* Solid waste scavenger community: an investigation in Bangkok, Thailand. *Asia Pac J Public Health* 1991;**5**:54-65.

43 Marteel-Parrish AE, Abraham MA. *Green Chemistry and Engineering: A Pathway to Sustainability*. Hoboken, NJ: Wiley 2013.

44 Haarman A, Gasser M. *Managing hazardous additives in WEEE plastic from the Indian informal sector: A study on applicable identification & separation methods*. Gallen, Switzerland: Sustainable Recycling Industries 2016.

45 GTZ. The waste experts: Enabling conditions for informal sector integration in solid waste management. *German Technical Cooperation Agency (GTZ)*. Eschborn, Germany 2010.

46 Yang H. China must continue the momentum of green law. *Nature* 2014;**509**:535-535.

47 Yang H, Huang X, Thompson JR*, et al.* Enforcement key to China's environment. *Science* 2015;**347**:834-5.

48 Bonner C. Waste pickers without frontiers: First international and third Latin American conference of waste pickers. 2008.

49 Medina M. The informal recycling sector in developing countries: organizing waste pickers to enhance their impact. *Gridlines* 2008;**44**:1-3.

50 Velis CA, Wilson DC, Rocca O*, et al.* An analytical framework and tool ('InteRa') for integrating the informal recycling sector in waste and resource management systems in developing countries. *Waste Manage Res* 2012;**30**:43-66.

51 Ojeda-Benitez S, Armijo-de-Vega C, Ramírez-Barreto ME. Formal and informal recovery of recyclables in Mexicali, Mexico: handling alternatives. *Resour Conserv Recy* 2002;**34**:273-88.